APPENDIX A. Band-Scanning Receiver Sensitivity Analysis

Each Leo One USA satellite uses a band-scanning receiver to identify clear uplink channels for assignment to subscriber terminals. The receiver's detection sensitivity is given by:

$$P_T = k + T_R + B_R + L_D + SNR_D - G_R + FSL - G_T$$

where P_T is the in-band transmit power sensitivity (dBW)

- k is Boltzman's constant, -228.6 dB(W/Hz/°K)
- T_R is the receiver noise temperature (dB-°K)
- B_R is the receiver noise bandwidth (dB-Hz)
- L_D is the detection loss (dB)
- SNR_D is the required SNR for detection (dB)
- G_R is the receiver antenna gain in the direction of the transmitter (dBi)
- FSL is the free space loss from the transmitter to the receiver (dB)
- G_T is the transmit antenna gain in the direction of the satellite (dBi)

The receiver system noise temperature is 738° K and the receiver noise bandwidth is 2.5 kHz. A 2 dB detection loss is assumed. An SNR of 13.3 dB provides a 99.9% probability of detection and a 1% false alarm rate for a 0.4 millisecond duration signal.

The satellite antenna is iso-flux with -2 dBi nadir gain and the satellite altitude is 950 km. At 460 MHz, the free space loss is 145.3 dB. Assuming 0 dBi transmit antenna gain in the direction of the satellite and no excess path loss, the band-scanning receiver can detect a -3.3 dBW (470 mW) in-band transmit power signal anywhere in the satellite footprint.

If the transmit signal bandwidth is greater than 2.5 kHz then a correction factor is required. To first order the detectable transmit power is given by the transmit signal bandwidth divided by 2.5 kHz, times 470 mW. For example, for a typical land mobile transmit signal bandwidth of 16 kHz, the detection sensitivity is 3 W.

At 149 MHz the transmit power sensitivities are 49 mW in a 2.5 kHz bandwidth and 315 mW for a 16 kHz LMS signal.

The band-scanning receiver is significantly more sensitive to longer duration signals. Figure A-1 shows the in-band transmit power sensitivity for signal durations up to 0.5 seconds. The band-scanning receiver can detect a 0.5 second duration, 460 MHz, 2.5 kHz bandwidth, 3.5 mW transmit power signal anywhere in the satellite footprint with 99.9% probability. For a 16 kHz signal the sensitivity is 22 mW.

At 149 MHz the transmit power sensitivities are 0.4 mW and 2.3 mW, for 2.5 kHz and 16 kHz signals, respectively.

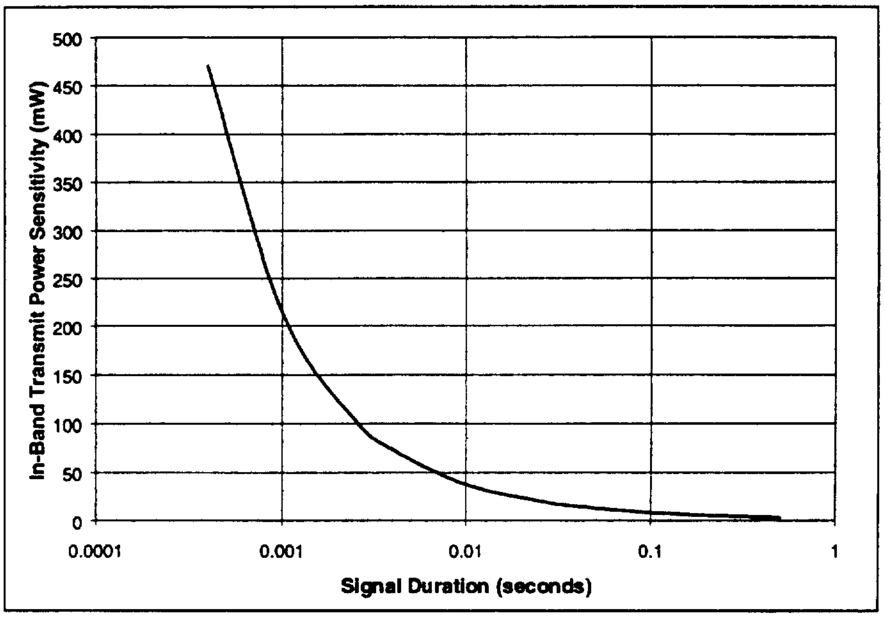

Figure A-1. Band Scanning Receiver Sensitivity as a Function of Signal Duration

APPENDIX B. Simulation Description

The results presented in Sections 3 and 4 were obtained using the simulations described in Sections B.1 and B.2, respectively. They represent several hundred hours of run time on a dual processor Sun Sparc20 workstation.

B.1 Interference from NGSO MSS MESs into Land Mobile Stations

The simulation determines the probability of interference assuming that dynamic channel assignment is not used. This worst case assumption provides an upper bound on the actual probability of interference for NGSO MSS networks with dynamic channel assignment.

The input parameters are:

1) Land Mobile Channelization Plan (25, 12.5 or 6.25 kHz) - Used to determine land mobile link center frequency and receiver IF bandwidth as shown in Table B-1.

Table B-1. Land Mobile Channelization Plans

Channelization Plan	IF Bandwidth
25 kHz	16 kHz
12.5 kHz	8 kHz
6.25 kHz	4 kHz

2) MES Uplink Data Rate (9.6, 4.8, or 2.4 kbps) - Used to determine the MES transmit spectrum as shown in Figure 2-1 and transmit power as shown Table B-2.

Table B-2. MES Transmit Powers

Data Rate	Transmit Power
9.6 kbps	7 W
4.8 kbps	3.5 W
2.4 kbps	1.75 W

3) MES Distribution (Uniform or Clustered)

4) MES Channel Selection (Random or Interstitial)

For a given set of input parameters, a sufficient number of ½-second trials are performed to insure that the computed probability of interference is reliable. For each ½- second trial the following steps are performed:

1. A land mobile transmitter location is randomly selected as the center of one of the 20 most populous cities in the CONUS.

2. The land mobile receiver location is randomly selected using a circular mass distribution from 0 to 20 km from the transmitter location.

3. A land mobile link center frequency, CF_{LM}, is randomly selected in a 1 MHz bandwidth based on the input land mobile channelization plan.

4. The land mobile receiver IF bandwidth, B_{IF}, is determined from the input channelization plan.

5. The distance between the land mobile transmitter and the land mobile receiver, d_{LM}, is computed.

6. 128 active MESs are randomly selected each ½-second over the CONUS using the input distribution, either uniform or clustered. This corresponds to over 22 million MES transmissions per day from the CONUS, which assumes that the NGSO MSS system is operating at 100% of theoretical capacity. This is another worst case assumption.

7. The distances, $d_{MES\text{-}LM}$, from each of the MESs to the land mobile receiver are computed.

8. Center frequencies, CF_{MES}, are randomly selected in a 1 MHz band for each of the MESs using the input selected method, uniform or interstitial.

9. The MES effective isotropic radiated power spectrum, $EIRP_0(f)$, is determined based on the input data rate.

10. The carrier-to-noise-plus-interference ratio is computed as follows:

$$C/(N+I) = \frac{\dfrac{10^{3.204} W}{d_{LM}^{4}}}{10^{-15.07} W + \displaystyle\int_{CF_{LM}-\frac{B_{IF}}{2}}^{CF_{LM}+\frac{B_{IF}}{2}} \sum_{MESs} \frac{10^{2.815} \cdot EIRP_0(CF_{MES} - f)}{d_{MES-LM}^{4}} \, df}$$

11. If C/(N+I) is less then 10.7 dB then the trial is deemed to have resulted in interference.

The probability of interference is computed as the ratio of the number of trials resulting in interference divided by the total number of trials.

For cases with low LMS traffic loading, the probability of interference is reduced by the Erlang factor for the channel.

B.2 Interference from Land Mobile Stations into NGSO MSS Satellites

The simulation determines the number of land mobile stations in the CONUS that can operate in the shared spectrum and still provide a minimum average of 6 clear channels per satellite for the NGSO MSS uplinks. This worst case assumption provides a lower bound on the number of land mobile stations that operate in the shared spectrum while still allowing the NGSO MSS network to operate at 36% of theoretical capacity.

The input parameters are:

1) Land Mobile Channelization Plan (25, 12.5 or 6.25 kHz) - Used to determine land mobile station center frequency grid, and land mobile transmit spectrum as shown in Figure 2-2.

2) MES Uplink Data Rate (9.6, 4.8, or 2.4 kbps) - Used to determine the NGSO MSS uplink center frequency grid as shown in Table B-3.

Table B-3. MES Uplink Channel Bandwidths

Data Rate	Channel Bandwidth
9.6 kbps	15 kHz
4.8 kbps	10 kHz
2.4 kbps	5 kHz

3) Amount of shared spectrum (1 MHz or 5 MHz).

4) Land mobile station average activity factor (0.01, 0.003, 0.001, or 0.0003 Erlang).

For each set of input parameters, the following steps are performed:

I. The initial number of land mobile stations is set to 1,000.

II. The land mobile stations are randomly distributed across the CONUS.

III. The land mobile transmitter effective isotropic radiated power spectrum, $EIRP_0(f)$ is determined based on the input land mobile channelization plan.

IV. The NGSO MSS satellite system uplink channel bandwidth, BW, is determined based on the input MES uplink data rate.

V. For each trial, the NGSO MSS satellite constellation is randomly rotated in time, a sufficient number of trials are performed to insure that the computed number of land mobile stations is reliable. The following steps are performed:

A. For each land mobile station, a transmit center frequency, CF_{LMS}, is randomly selected in the input amount of shared spectrum, 1 MHz or 5 MHz, based on the input land mobile channelization plan.

B. For each land mobile station and for each NGSO MSS satellite the Doppler frequency shift, $\Delta f_{Doppler}$, is computed.

C. For each NGSO MSS satellite and for each NGSO MSS uplink channel center frequency, CF_{CH}, in the input amount of shared spectrum, the interference-to-noise ratio is computed as follows:

$$(I/N)_{CH} = 10^{6.25} \cdot \int_{CF_{CH}-\frac{BW}{2}}^{CF_{CH}+\frac{BW}{2}} \sum_{LMSs} EIRP_0(CF_{LMS} + \Delta f_{Doppler} - f)\,df$$

d) For each NGSO MSS satellite, the number of clear channels is computed as the sum of those with I/N < 10 dB.

4. If the minimum of the computed numbers of clear channels is greater than 6, then the number of land mobile stations is increased by 1,000 and the above procedure is repeated starting at step 2.

7. The process is completed when the maximum number of LMS stations that still allows for 6 clear channels is found.

ANNEX 4

DRAFT CPM REPORT TEXT
FOR SECTION 4.1. MOBILE SATELLITE SERVICE

4.1.1.1.1 Summary of Frequency Sharing Studies Between Non-GSO MSS Below 1 GHz Earth-to-Space Links and the Land Mobile Service and Analysis of Their Results

The ITU-R studied the technical and operational issues relating to sharing between the land mobile service and the non-GSO/MSS below 1 GHz. Sharing between the MSS and terrestrial fixed and mobile systems, in the uplink direction can be accomplished by designing the MSS systems to operate in either a narrow-band, frequency-agile fashion to coexist with terrestrial services, or with wideband, low-power density, spread-spectrum transmissions which will provide sufficient margin against interference. Both of these transmission techniques reduce the possibility of interference to systems that share the same spectrum. In addition, the nature of the data-only services provided by MSS systems and the markets served by them are amenable to incorporation of other interference reduction techniques such as short, sub-second length data bursts and low-duty cycle transmission. The mobility of the users also reduces the coupling that can occur between MESs and other services operating in the band.

In one study a non-GSO MSS network had the following major characteristics: 48 satellites in 8 orbital planes in 950 km altitude circular orbits; narrow-band frequency division multiplexing for the Earth-to-space transmissions; operation in a store-and-forward mode; transmissions within 500 ms frames containing digital packets; satellite use of a band scanning receiver to implement a dynamic channel activity assignment system that assigns unused channels to earth stations for uplink transmissions; and uplink data rates of 2.4, 4.8, and 9.6 kbps. The land mobile station was modeled with the following characteristics: an analogue, frequency modulation system (or digitally modulated, binary-FSK system); a vertically polarized antenna having 0 dBi gain towards the satellite; 10 meter antenna height product (consistent with ITU-R Recommendation M.1039-1); minimum received signal power assumed to be -140 dBW; and channel bandwidths of 6.25, 12.5 and 25.0 kHz. These characteristics are shared by certain land mobile systems currently operating in frequency bands ranging from 138 MHz to 869 MHz. The analysis assumed multiple worst case conditions: 1) non-GSO MSS mobile earth stations (MESs) transmitting at 100% of capacity, 24 hours per day, 2) terrestrial stations and non-GSO MSS MESs geographically clustered in the same areas, and 3) dynamic channel avoidance not employed. For the worst case conditions stated, if the land mobile station is operated at push-to-talk rates of 0.01 Erlang, the land mobile station would experience a mean time between interference events of 2.5 days. For a variety of channelization plans, MES bit rates, and terminal distributions, the mean time between interference events for a typical land mobile user was found to range from 10 hours to 21 months. The land mobile user would observe the interference event as a single, short term event. Since in general the non-GSO MSS network will be able to identify active mobile channels, the actual interference from non-GSO MSS MESs into a given land mobile station will be much less than that calculated under the worst case assumptions used.

Narrow-band non-GSO MSS networks may use dynamic channel assignment techniques to avoid channels being actively used by land mobile stations. A Dynamic Channel Assignment Technique (DCAAS) could be used as described in Annex 2 to ITU-R Recommendation M.1039 [8/22]. This technique identifies all active land mobile channels so that there is virtually no possibility of interference from land mobile stations into non-GSO MSS satellites. Analysis based on observed band use worldwide shows there would be a sufficient number of unused, clear channels available to support non-GSO MSS operations. A simulation program was used to determine the number of land mobile stations within the satellite footprint that can operate in the shared spectrum and still provide a minimum average of 6 clear channels per satellite for the non-GSO MSS uplinks. Four different land mobile station activity factors, three land mobile channelization plans, and three MES uplink data rates were considered. The results indicate that with 6.25 kHz land mobile system channelization, 2.4 kbps MES uplink data rate, and 0.003 Erlang activity factor, 190 000 terrestrial mobile stations could operate within the satellite footprint (12 million km^2) and still leave a minimum of 6 clear channels for MES uplink transmission in 1 MHz of shared bandwidth. For the same conditions, but in 5 MHz of shared bandwidth, 1.5 million terrestrial mobile stations could operate. These results indicate that frequency sharing, as modeled, could allow the non-GSO MSS below 1 GHz networks to find sufficient clear channels to operate. The use of DCAAS also practically eliminates potential for interference between MESs and terrestrial services, as well, since occupied channels are avoided.

4.1.1.2 Methods to satisfy the Agenda item and their relative advantages

The results of the analyses and simulations presented to date show that frequency sharing between narrow-band, Earth-to-space links for non-GSO MSS below 1 GHz networks and land mobile services would produce infrequent interference to the land mobile service. An additional result is that frequency sharing between narrow-band non-GSO MSS below 1 GHz networks and land mobile services could allow the non-GSO MSS networks to find sufficient clear channels in the bands modeled to operate Earth-to-space. The conclusion reached to date is that it is feasible for narrow-band non-GSO MSS uplinks using DCAAS to share spectrum with land mobile services in bands below 1 GHz where both the MSS and the land mobile system characteristics are as modeled, and where 0.1% additional availability degradation is acceptable.

4.1.1.3 Regulatory and procedural considerations

Recommendation ITU-R M.1039 addresses the use of dynamic channel activity assignment techniques to avoid MSS system use of channels that are in active use by land mobile systems. An appropriate radio regulation provision could make specific reference to this Recommendation in regard to narrow-band MSS systems.

INTERNATIONAL TELECOMMUNICATION UNION

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STUDY GROUPS

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Sub-Working Group 8D3A-6

INFORMATION DOCUMENT IN SUPPORT OF CPM TEXT TO BE ATTACHED TO THE REPORT OF THE CHAIRMAN OF WP-8D

SPECTRUM DEMAND FOR NON-GSO MSS BELOW 1 GHz SERVICES

1 Introduction

In its considerings, Resolution 214 of WRC-95 "indicated that, in order to meet projected MSS requirements below 1 GHz, a range of an additional 7 to 10 MHz will be required in the near future." This information document summarizes the results of a study conducted to make more certain and more definitive future spectrum requirements for the MSS below 1 GHz.[1]

While any market assessment at such an early stage of development is uncertain, the demand scenarios constructed based on the study results suggest strong potential demand for NGSO MSS services. How much of this business potential is achieved will depend, among other factors, on the availability of sufficient spectrum worldwide to enable the development of these systems.

In addition to the study's market demand findings, this paper calculates the bandwidth for service links and feeder links that would be required to carry this traffic.

1.1 Scope

While there is broader potential for NGSO MSS satellite services, the scope of the study was concentrated on the following five application areas:

- Automated Meter Reading (AMR) for utilities industries
- Asset Tracking for the transportation and freight industries
- Vehicle Messaging for commercial vehicles and the trucking industry
- Personal Messaging for mobile individuals
- Remote Monitoring and Supervisory Control and Data Acquisition (SCADA) for oil and gas pipeline operators and individuals.

[1] *Business Opportunities in the Little LEO Satellite Services Market*; A Report Prepared for Final Analysis Communication Services Inc. by Deloitte & Touche, a major international consulting firm.

Analysis of the growth rates and drivers in the selected application areas was based on the seven-year time frame 1996-2002.

1.2 Methodology

Due to the early stage of development of NGSO MSS technology, the study relied heavily on in-person and telephone interviews to create the fact base. In all, more than 30 face-to-face interviews and more than 50 telephone interviews were conducted with three categories of people:

- End users in the target application areas
- Functional competitors and/or industry resellers (Big LEO service providers, terrestrial wireless communications providers)
- Industry observers (industry analysts in the financial community, industry consultants, journalists (trade) and equipment suppliers).

These created an up-to-date fact base, permitting less reliance on market reports or company brochures that might be outdated and/or set overly optimistic expectations for market demand or for end-use costs in adopting NGSO MSS satellite technology.

The interviews were supplemented by an extensive data-gathering effort based on secondary research sources - company documents, market research reports, and searches of trade journals.

In international markets for which data are not available, estimates were made based on benchmarks derived from known markets with similar economic, regulatory, and competitive environments.

1.3 Analysis

The overall market size was estimated based on the installed base of terminals in each application area. The growth rate applied was based on either historical growth trends or published growth projections. The addressable market size was based on an assessment of the NGSO MSS value proposition and its fit with end user technology selection criteria. To avoid "double-counting," the addressable market is an estimate of the number of users that could best be served via NGSO MSS technology. In each application area, alternative competitive technologies have been taken into account.

For each potential application area, the addressable market for NGSO MSS services is that portion of the total available market where NGSO MSS features and capabilities are likely to be more attractive than that of the substitute technologies, as perceived by end users and providers of substitute technologies.

The work performed by the study involved development of forward-looking demand scenarios based on interviews with industry participants and secondary data sources.

2 Addressable markets

The following information sets were developed for each market:

- Total market in units by year and region
- NGSO MSS addressable markets
- End-user technology selection criteria

- Assessment of functional substitutes
- NGSO MSS share of market
- Size of the NGSO MSS addressable market by year and by region.

For each market, the study assessed the ability of a variety of incumbent terrestrial and satellite-based wireless technologies to meet customer needs.

AUTOMATED METER READING

The number of utility meters was determined by taking the total installed base of conventional utility meters. In international markets for which data was not available, the study estimated the total number of meters based on benchmarks for the number of meters per capita for known markets with similar economic, regulatory and competitive environments. Next, seven-year projections were developed based on historical growth rates for the size of the installed base.

ASSET TRACKING

Estimates of the total number of commercial vehicles, cargo trailers and shipping containers were developed by determining the total installed base of commercial vehicles, cargo trailers and shipping containers in the world.

VEHICLE MESSAGING

Estimates for the total number of truck tractors, commercial vehicle and ships which could be equipped with messaging terminals were developed first by determining the total installed base of tractor trailers, commercial vehicles and ships in the world. In international markets for which data was unavailable, the total number of such vehicles was estimated based on benchmarks for the number of vehicles per capita for known markets with similar economic, regulatory and competitive environments. Growth projections were developed based on historical growth rates or, where available, industry projections for specific types of vehicles and ships.

PERSONAL MESSAGING

Estimates of the total number of personal messaging devices in North America and international markets are based on numerous industry data sources, including Mtel Corporation (Skytel), RAM Mobile Data, and Motorola.

SCADA

For SCADA, the study focused only on oil and gas providers. Determination of the total number of compressor-station SCADA remote terminal units was based on known data for a large number of oil and gas providers in North America, as well as an estimate for compressor-station remote terminal units based on North American benchmarks for the average number of remote terminal units per mile of pipeline. Industry sources relied on for data include the Oil and Gas Journal, as well as data published by the Petroleum Institute giving an overview of existing pipelines worldwide and projections for new pipeline construction and retirements over the next decade.

SUMMARY

The market study identified 42.9 million potential users for NGSO MSS services in the five application areas studied. Table 2-6 provides a summary of this projected market by area of application and regional use.

TABLE 2-6

Projected world market for NGSO MSS technology major application areas for the period 1996-2002

	North America	Europe	Latin America	Asia	Africa	Global Total
Automated Meter Reading	14,874	4,830	1,888	8,703	239	30,534
Remote Asset Tracking	844	296	77	N/A	N/A	>1,347
Vehicle Messaging	1,403	645	172	166	17	2,405
Personal Messaging	1,630	2,569	966	3,368	103	8,636
SCADA	12	8	2	6	1	29
Regional Total	18,763	8,348	3,105	>12,243	>360	>42,951

All numbers are in thousands.

N/A = not available.

2.2 Assessment of competitive technologies

To determine the addressable market for NGSO MSS services, functional requirements were identified for each application area, and then a variety of competitive, alternative terrestrial and satellite-based wireless technologies were identified and assessed as to their ability to meet the identified user needs.. The alternatives substitutes included in the study, and the requirements identified for each application are as follows:

Automated Meter Reading

Requirements: Low Cost per Read; Current Value-added Functionality; Compatibility with Existing Systems, Minimal Technology Risk; Prospect for Future Value-Added Capabilities; Rapid Installation and Deployment

Competitive Technologies: Manual (visual) reads, hand-held radio, mobile radio, fixed cellular networks

Asset Tracking

Requirements: Geographic Coverage and Flexibility; System Reliability; Low Operating Costs; Low System Costs; Rapid Updating

Competitive Technologies: GEO, cellular networks, specialized mobile radio data networks, Big LEO

Vehicle Messaging

Requirements:	Footprint of Coverage Area; Application Features and Functions; Near Real-time Connectivity; High Data-rate; Low Messaging and Terminal Costs; Small Terminal Size
Competitive Technologies:	GEO, cellular networks, specialized mobile radio data networks, Big LEO

Personal Messaging

Requirements:	Footprint of Coverage Area; Application Features and Functions; Near Real-time Connectivity; High Data Rate Capability; Low Messaging and Terminal Costs; Small Terminal Size
Competitive Technologies:	Specialized mobile radio data networks, cellular networks, GEO, Big LEO

SCADA

Requirements:	High Reliability and Redundancy; Real-time; Secure Communications; Capacity to Handle Peak Traffic; Ease of Integration; Speed to Deploy
Competitive Technologies:	Microwave, leased telephone circuits, GEO, fixed cellular networks

The market research studies, which resulted in the numbers of prospective users shown here for the five application areas for NGSO MSS services, took into account the cost and features the competing, alternative technologies listed above. Thus, the projected market shown in Tables 2-1 through 2-6 is the net market for NGSO MSS services. That is, these tables represent the overall number of prospective users for these services, after subtracting for those that would use competitive, alternative technologies.

3 Required bandwidth for NGSO MSS

For technical and economic reasons, this study is focused on frequency bands below 1 GHz for NGSO MSS service links. Using nearly omnidirectional gain patterns for the Mobile Earth Station (MES) antennas, the lower free-space propagation losses at VHF and UHF result in positive link margins using moderate transmitter powers (on the order of 5 - 10 W). These factors minimize the cost of MES and make them economically viable. However, the higher free-space losses at frequencies slightly above 1 GHz can be overcome for feeder links by using higher transmitter power and higher gain, narrow-beam tracking antennas at feeder link stations.

Some of the application areas summarized in Table 2-6 are primarily one-way. For example the bulk of the traffic on the service links for Automated Meter reading and remote tracking, will be from mobile earth stations to a satellite (i.e. service uplinks). In other application areas (e.g. Messaging) there will be more or less equal traffic on the service links in both directions between the satellite and mobile earth stations (i.e. on service uplinks and service downlinks). Similarly, traffic on feeder links will differ in the two directions of transmission. Therefore, spectrum requirements will be calculated separately for the four links between satellites and earth stations.

The first step in converting traffic demand into spectrum is to calculate the bandwidth that would be required in each of the four directions of transmission if that spectrum were to be used only by NGSO MSS systems. (This unlikely assumption is made only as a first step in calculation of the spectrum that would be required on a shared basis. All current MSS NGSO allocations are in bands shared with other services.)

Since all MSS NGSO spectrum will undoubtedly be shared with other services, the overall allocation to the several services in shared bands must obviously be larger than the spectrum required by any one of them. Thus, the spectrum required for MSS NGSO systems on an exclusive basis must be increased by a factor that will take into account the traffic requirements of other services; the requirement that NGSO MSS systems use only those channels within a shared band that will not cause interference to, or receive interference from, those other services; and the difficulty created by the wide range of domestic assignments made in shared bands by different countries around the world.

As discussed below, this study uses a multiplication factor of 5.0 to account for shared frequency usage, based on current terrestrial cellular experience.

However, even this multiplication factor of 5 does not take into account another aspect of the shared use of spectrum by systems providing global service that would increase the amount of spectrum that must be allocated to a service, above that dictated by the two shared-use factors discussed above. That is the wide difference in domestic allocations and assignments made by different countries around the world. For example, if 1 MHz were required for NVNG MSS, and a certain 5-MHz band were to be designated to be shared by it and other services on a worldwide basis, that particular 5-MHz band might be much more heavily used in some countries than others, or might be used in some countries by services that would make sharing difficult. That would result in NVNG MSS systems not being able to find enough non-interfering, and non-interfered-with channels in those countries. The solution would be to designate a wider band for sharing than the 5 MHz in the example above. The resulting use made by NVNG MSS systems in the larger band would still be only 1 MHz, but it would be a different 1 MHz in different countries.

3.1 Required bandwidth for NGSO MSS service uplinks

To estimate the total required uplink bandwidth, the following assumptions are made:

- The allocated frequency band will be used on a shared basis.
- The modulation type is GMSK, which results in a channel bandwidth 1.5 times the baud rate.[2]
- The average packet size is 128 bytes, or 1 024 bits, including overhead.
- Data transmission is uniformly distributed over the total available transmission time. (Several factors justify this conservative assumption. For one, typical NGSO satellites have footprints with a diameter of about 5 000 km, which encompasses three time zones. Therefore, traffic peaks during the Busy Hour will be spread out. Secondly, a major

[2] The multiplier of 1.5 for GMSK modulation is assumed only for the purpose of calculating required bandwidth for initial NVNG MSS systems, and is not meant to imply that modulation methods having greater efficiencies of bandwidth utilization will not be employed or required in future systems as usage increases. For example, in the United States, bandwidth efficiencies of 0.769 bits/Hz (that is, a multiplier of 1.3) are required now for terrestrial Land Mobile systems.

application of these systems, Automated Meter Reading, can be scheduled for transmission during off-peak hours, further reducing the peak-to-average factor.) Any adjustment factor introduced to account for non-uniform distribution of traffic would increase the required bandwidth over the estimates made here.

- Each user can see at least one satellite every time it transmits. More satellites in sight will not reduce the bandwidth requirements, since it is assumed that the bandwidth will be shared by all satellite systems to provide service to all users. If coverage is not continuous, the required bandwidth would have to be increased, since the same number of packets would have to be transmitted in less time.

- To account for repeats of incomplete or missed transmissions, an adjustment factor of 1.35 is used.

- To account for shared frequency usage - that is, if the band will be shared with other services that will take up some of the capacity and that must be protected from interference - the shared band must be wider than that required to carry only the MSS traffic. An adjustment factor of 5 is used in this analysis, based on current terrestrial cellular experience. Assume that in a 4-MHz bandwidth, 8 000 existing terrestrial users are within interference range of a mobile earth station (MES). Assume further that each such existing user transmits for 6 minutes during an 8-hour period each day. The total traffic generated by these users would be:

$$\frac{(8\,000 \times 6)}{(8 \times 60)} = 100 \text{ Erlangs},$$

which corresponds to 128 trunks (channels) being utilized with a grade of service of P = 0.001.[3] Now, if the 4-MHz total bandwidth is divided into 160 channels of 25 kHz each, then 32 channels (160 - 128) would be available for use by MSS. That is one-fifth, or 20% percent, of the total number of 160 channels. This means that for an MSS allocation to be shared with existing users having the usage pattern assumed here, the allocation would need to be five times that of an exclusive allocation. Hence, a multiplication factor of 5 is used in the calculation of required bandwidth to account for sharing with existing terrestrial users[4].

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[3] The grade of service is the ratio of the number of calls that are not completed at first attempt, to the total number of attempts to establish a connection during a specific period of time, usually the Busy Hour.

[4] Recent tests made on an operational NVNG MSS satellite equipped with DCAAS revealed that within a footprint covering all of the United States and portions of Canada and Mexico, between 150 to 200 2.5 kHz interstitial channels out of a total of 800 channels in the 148 MHz band appeared to be unused by terrestrial mobile users for varying lengths of time (with a mean duration of about 20 seconds). That would indicate a multiplication factor of between 4 and 5 for shared use. In more heavily used bands the multiplication factor for shared used might be considerably higher.

Using these assumptions, the required channel capacity is calculated from the following equation:

$$\text{Channel Capacity} = \frac{(\text{Num of users}) \times (\text{Num of packets/day/user}) \times (1\,024 \text{ bits/packet})}{\text{Total Transmission Time}} \text{ Bits/Second}$$

Where:

Total Transmission Time = (24 Hours/Day) x (60 Minutes/Hour) x (60 Seconds/Minute) = 86400 Seconds/Day

Table 3-1 shows the required channel capacity for each service category based on the projected number of users for all regions. There may be other projections based on different assumptions that would increase the required channel capacity. In this regard, the following is a conservative estimate.

TABLE 3-1

Channel capacity requirements

		North America		Europe		Latin America		Asia		Africa	
	Packets/ Day User	Users (kb/s)	Channel capacity	Users (kb/s)	Channel capacity	Users (kb/s)	Channel capacity	Users (kb/s)	Channel capacity	Users (kb/s)	Channel capacity
Automated Mtr. Reading	1	14,874,000	176.28	4,830,000	57.24	1,888,000	22.38	8,703,000	103.47	239,000	2.83
Remote Tracking	48	844,000	480.14	296,000	168.40	77,000	43.80	N/A	N/A	N/A	N/A
Vehicle Messaging	4	1,403,000	66.51	645,000	30.58	172,000	8.15	166,000	7.87	17,000	0.81
Personal Messaging	32	1,630,000	618.19	2,569,000	974.32	966,000	366.36	3,368,000	1277.35	103,000	39.03
SCADA	N/A	N/A		N/A		N/A		N/A		N/A	
Total			1341.12		1230.54		440.69		1388.69		42.67

N/A = not available at this time.

The largest capacity total for each region determines the channel capacity requirement. Although Asia has the highest estimate for channel capacity, the entire region cannot be covered by one footprint. In order to calculate the required bandwidth for Little LEO systems, it is necessary to consider a region that has the required channel capacity and at the same time is covered by one footprint. Since the required channel capacity for North America is comparable to that of Asia, and North America is covered by one footprint, the required channel capacity for North America has been used to calculate the required bandwidth for Little LEO systems. Thus assuming GMSK modulation and a multiplication factor of 1.35 to account for incomplete or missed transmissions, the total required uplink bandwidth is:

$$\text{Bandwidth}_{\text{exclusive}} = 1341.12 \times 1.5 \times 1.35 \text{ » } 2.72 \text{ MHz}$$

This bandwidth must be increased by the factor of 5 if it is shared with other services:

$$\text{Bandwidth}_{\text{shared}} = 2.72 \times 5 = 13.6 \text{ MHz.}$$

Therefore, 13.6 MHz of bandwidth is the minimum required for uplinks on a shared basis.[5]

3.2 Required bandwidth for NGSO MSS service downlinks

To estimate the total required bandwidth for NGSO MSS downlinks below 1 GHz, the following assumptions are made:

- The data received for Vehicle Messaging and Personal Messaging will be transmitted via service downlink.
- Automated Meter Reading and Remote Asset Tracking do not require service downlinks.
- Each user can see at least one satellite every time it transmits or receives. More satellites in sight will not reduce the bandwidth requirements, since the bandwidth will be shared by all satellite systems.
- The allocated frequency band will be used on a shared basis, using coordination and Exclusion Zone methods.
- The modulation is GMSK, which results in a channel bandwidth 1.5 times the baud rate[2].
- To account for repeats of incomplete or missed transmissions, an adjustment factor of 1.35 is used.
- To account for shared frequency use, a multiplication factor of 5 is used. (See discussion in Section 3.1.)
- Downlink channel capacity needed for polling or frequency assignment to frequency-agile terminals is negligible compared to the channel capacity needed for uplink transmissions. (Downlink polling and frequency assignment will need a maximum of only 12 bytes per terminal, compared with a minimum uplink data length of 128 bytes for subscriber-generated information.)

Using these assumptions, the required channel capacity and bandwidth for service downlinks based on the projected number of users would be as follows:

$$\text{Channel Capacity} = 618.19 + 66.51 = 684.7 \text{ kb/s}$$

Therefore, the total bandwidth required for service downlinks on an exclusive basis is

$$\text{Bandwidth}_{\text{exclusive}} = 684.7 \times 1.5 \times 1.35 = 1.4 \text{ MHz}$$

And the shared bandwidth requirement is

$$\text{Bandwidth}_{\text{shared}} = 1.4 \times 5 = 7 \text{ MHz.}$$

This calculation is made for North America; Asia may require twice as much bandwidth, since the projected demand for messaging in Asia is twice that for North America.

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[5] The additional bandwidth for uplinks will be this total minus the spectrum now available for NGSO MSS uplinks.

3.3 Required bandwidth for NGSO MSS feeder-links

To estimate the total required bandwidth for NGSO MSS feeder links above 1 GHz, the following assumptions are made:

- The data received from Automated Meter Reading at the satellite will be sent to the ground station via the feeder downlink.
- The data received from Remote Asset Tracking at the satellite will be sent to the ground station via the feeder downlink.
- The data for Vehicle Messaging and Personal Messaging may have to utilize either feeder uplink or feeder downlink. In order to calculate the required channel capacity, both cases are considered.
- Each user can see at least one satellite every time it transmits or receives. More satellites in sight will not reduce the bandwidth requirements, since it is assumed that the bandwidth will be shared by all satellite systems to provide service to all users.
- The allocated frequency band will be used on a shared basis through the use of local coordination and exclusion zone methods. Therefore, no sharing factor need be used in the calculation of the required bandwidth for feeder links.
- Coordination and geographic separation of Earth stations can make the entire allocated bandwidth available to each satellite system.
- The modulation is GMSK, which results in a channel bandwidth 1.5 times the baud rate. The rapid roll-off of GMSK signals outside the occupied bandwidth facilitates sharing among satellite systems and with fixed services. This is particularly important for frequency bands near those allocated to the Radio Astronomy Service, which can only tolerate extremely low interference (-255 dBW/m^2/Hz).
- To account for repeats of incomplete or missed transmissions, an adjustment factor of 1.35 is used.
- Channel capacity needed for Telecommand, Telemetry and Control (TT&C) will be negligible compared to the channel capacity needed for transmission of subscriber-generated information.

Using these assumptions, the required channel capacity and bandwidth for feeder links based on the projected number of users would be:

Feeder Uplink:

Channel Capacity = 618.19 + 66.51 = 684.7 kb/s,

Required Bandwidth = 684.7 x 1.5 x 1.35 = 1.4 MHz

Feeder Downlink:

Channel Capacity = 176.28 + 480.14 + 66.51 + 618.19 = 1341.12 kb/s

Required Bandwidth = 1341.12 x 1.35 x 1.5 = 2.7 MHz

Therefore, the total bandwidth required for feeder links is 1.4 + 2.7 = 4.1 MHz.

4 Conclusion

Based on market studies of the demand for NGSO MSS services, and reasonable assumptions for calculating the spectrum required to transmit that traffic, a minimum of 20.6 MHz of bandwidth shared with other services will be required for service links in both directions of transmission, and 4.1 MHz for feeder links in both directions, as shown in Table 4-1. To determine the additional spectrum required, the existing primary allocation of approximately 3.5 MHz must be subtracted from the total required spectrum of 24.7 MHz. This leaves an additional requirement of about 21 MHz.

TABLE 4-1

Bandwidth required for NGSO MSS service and feeder links

	Bandwidth Required (MHz) If Exclusive	**Bandwidth Required (MHz) If Shared***
Service Uplinks	2.72	13.6
Service Downlinks	1.4	7.0
Service Link Total:	**4.12**	**20.6**
Feeder Uplinks		1.4
Feeder Downlinks		2.7
Feeder Link Total:		**4.1**
*NOTE - The bandwidth of allocations must be wider than the shared bandwidths shown in this column, as discussed in Section 3, above.		

TABLE 2

Required bandwidth

	Bandwidth Required (MHz), If Exclusive	**Bandwidth Required (MHz), If Shared ***
Service Uplinks	2.72	13.6
Service Downlinks	1.4	7.0
Service Link Total:	**4.12**	**20.6**
Feeder Uplinks		1.4
Feeder Downlinks		2.7
Feeder Link Total:		**4.1**
*NOTE - The bandwidth of allocations must be wider than the shared bandwidths shown in this column because of the differences in domestic allocations, and the extent of their use in different parts of the world.		

The MSS allocation requirements include both service and feeder links (which usually operate within the service bands). In general, the inbound and outbound allocations should be approximately balanced for CDMA systems. A wider uplink allocation, however, leads to a more benign sharing situation; the wideband MSS system can operate with a lower power density by spreading over wider bandwidths. One system, with FDMA uplinks and TDMA downlinks requires approximately five times the downlink bandwidth as uplink bandwidth. Narrow band MSS systems with dynamic channel selection will occupy any given subchannel less often and will require a greater bandwidth to achieve a given message rate. Thus, the uplink and downlink allocations do not necessarily have to be equal. Note that the current studies show that on a worldwide basis an average of 3.2 million non-GSO MSS users would be provided service in each 1 MHz of bandwidth for uplinks and 6.1 million users per MHz for downlinks, when the data rates and frequency of use among the various users are taken into account.

In view of the requirements just noted, there is unlikely to be sufficient spectrum available beginning in the year 2000 to accommodate the requirements of the MSS Below 1 GHz service. For systems planned to be implemented around the year 2000 and later, there does not currently appear to be sufficient worldwide access in the available bands for such systems to grow and achieve commercial viability. Given the time required to develop and construct satellite systems, an additional 21 MHz (24.7 MHz minus the existing 3.5 MHz) on a worldwide basis is required in the immediate future if the requirements for the non-GSO MSS below 1 GHz are to be met.

WRC-97 Advisory Committee
Fact Sheet

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Document Title: Frequency Sharing Between Non-GSO MSS (Narrowband Earth-to-Space Links) and LMS Systems.

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Purpose/Objective:

To provide technical studies and analyses that pertain to frequency sharing between non-GSO MSS networks and land mobile systems below 1 GHz.

- Include digitally modulated systems in analyses and apply analysis to several frequency bands below 1 GHz.
- Provide information on performance of digital dynamic channel assignment technique.

To provide reference to a PDNR, "Method for the statistical modeling of frequency sharing between stations in the mobile service below 1 GHz and FDMA non-GSO MSS mobile earth stations."

Abstract:

This paper presents results of studies that show the feasibility of non-geostationary orbit mobile satellite service (non-GSO MSS) systems (narrowband earth-to-space links) sharing the same frequency band with mobile transceivers in land mobile service (LMS) systems. This paper is an expansion of earlier analyses in that digitally modulated LMS systems are included in the analysis, and the analysis is applied to several frequency bands below 1 GHz.

Section 2 characterizes the sharing environment. Section 3 describes a channel assignment method that allows the satellite system to occupy channels that are temporarily unused by the LMS systems. Later subsections present probability of interference calculations that show the potential interference to be rare. Annex 1 presents an ITU-R Preliminary Draft New Recommendation on statistical modeling of frequency sharing between stations in the LMS and FDMA NGSO MSS earth stations. Annex 2 presents modeling and simulation results that demonstrate low probabilities of interference. Performance of a digital dynamic channel assignment technique is also given in Annex 2. Annex 3 provides draft WAC-97 Report text that deals with frequency sharing between LMS and non-GSO MSS systems.

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FREQUENCY SHARING BETWEEN NON-GSO MSS (NARROWBAND EARTH-TO-SPACE LINKS) AND LMS SYSTEMS

1. Introduction

Resolution 214 (WRC-95) resolves 1) "that further studies are urgently required on operational and technical means to facilitate sharing between the non-GSO/MSS and other radiocommunication services having allocations and operating below 1GHz;" and 2) "that the 1997 World Radiocommunication Conference (WRC-97) be invited to consider, on the basis of the results of the studies referred to in resolves 1 above, additional allocations on a worldwide basis for the non-GSO/MSS below 1 GHz." This paper presents results of studies that show the feasibility of non-geostationary orbit mobile satellite service (non-GSO MSS) systems (narrowband earth-to-space links) sharing the same frequency band with mobile transceivers in land mobile service (LMS) systems. The analysis in this paper includes digitally modulated LMS systems, and the analysis is applied using LMS system characteristics common to several frequency bands below 1 GHz.

Section 2 characterizes the sharing environment. Section 3 describes a channel assignment method that allows the satellite system to occupy channels that are temporarily unused by the LMS systems. Later subsections present probability of interference results that show the potential interference to be rare. Annex 1 to this paper presents an ITU-R Preliminary Draft New Recommendation, "Method for the Statistical Modeling of Frequency Sharing Between Stations in the Mobile Service Below 1 GHz and FDMA Non-Geostationary Satellite Orbit (Non-GSO) Mobile Earth Stations", which incorporates the statistical modeling techniques for LMS/MSS sharing presented in this paper. Annex 2 is the detailed analysis that supports the PDNR in Annex 1 and presents the statistical modeling and simulation results that demonstrate low probabilities of interference. Performance of a digital dynamic channel assignment technique is also given in Annex 2. Annex 3 provides draft CPM Report text for section 4.1.1.1 on the subject of LMS/MSS frequency sharing below 1 GHz. This text may be appropriate for the WAC-97 Report.

2. Sharing environment

The 148-149.9 MHz, 455-456 MHz, and 459-460 MHz bands are currently allocated for non-GSO MSS uplinks and for land mobile service links on a co-primary basis. Other bands below 1 GHz that are allocated to the land mobile service are also being considered for allocation to the non-GSO MSS on a co-primary basis. Thus there is the potential for interference, both from non-GSO MSS Mobile Earth Stations (MESs) into land mobile stations and from land mobile stations into non-GSO MSS satellites.

2.1 Non-GSO MSS network

The example non-GSO MSS network used in the analysis has the following characteristics: 48 satellites in 8 orbital planes inclined 50 degrees to the equator; each plane contains six equally spaced satellites in 950 km altitude circular orbits; narrowband frequency division multiplexing for the Earth-to-space transmissions; operation in a store-and-forward mode; transmissions within 500 ms frames containing digital packets; satellite use of a band scanning receiver to implement a dynamic channel activity assignment system (DCAAS) that assigns unused channels to earth stations for uplink transmissions; and uplink data rates of 2.4, 4.8, and 9.6 kbps. For the analysis it was assumed that the system was operating at maximum capacity over a specific geographic area, (for this study, 22 million Earth-to-space packet transmissions per day over the contiguous United States).

2.2 Land mobile system

The land mobile stations used in this analysis have the following characteristics: analogue, frequency modulation system (or digitally modulated, binary-FSK system); a vertically polarized antenna having 0 dBi gain towards the satellite; minimum received signal power assumed to be -140 dBW; and channel bandwidths of 6.25, 12.5 and 25.0 kHz. Additionally, low erlang loading (0.01 to 0.0003) on individual channels provides opportunity for short-term, intermittent use of the frequencies by the mobile satellite earth stations.

3. Band sharing using dynamic channel assignment techniques

Mobile satellite systems below 1 GHz can use the technique of dynamic channel assignment to allow mobile earth stations to communicate effectively in the presence of approximately co-channel uplink interference from mobile transmitters. A receiver in the satellite monitors the entire shared frequency band and determines which segments of the spectrum are currently being used by the LMS system or for non-GSO MSS uplinks. The identified clear channels are available for assignment to non-GSO MSS uplinks. The LEO-L MSS system design uses a digital dynamic channel assignment technique that performs fast Fourier transform (FFT) processing in the satellite which allows the MSS uplink channels to be re-assigned (of the order of every 0.5 s) in response to measured channel availability. The band-scanning receiver sensitivity analysis in Appendix A of Annex 2 shows that the band-scanning receiver to be used by LEO-L can detect a 0.5 second duration, 460 MHz, 2.5 kHz bandwidth, 3.5 mW transmit power signal anywhere in the satellite footprint with 99.9% probability. For a 16 kHz signal the sensitivity is 22 mW. At 149 MHz the transmit power sensitivities are 0.4 mW and 2.3 mW, for 2.5 kHz and 16 kHz signals, respectively.

3.1 Operation of dynamic channel assignment techniques

With the band-scanning receiver on board the satellite, there is very little chance for interference from mobile earth stations to land mobile system receivers. There are, however, several circumstances where the dynamic channel assignment technique would fail to identify an active LMS channel: 1) LMS power level below the detection threshold of the satellite band-scanning receiver, 2) blockage on the path from the LMS transmitter to the satellite so the received signal level is not high enough to be detected, 3) a LMS transmitter begins operation on a channel during a MSS transmission on what had previously been measured as a clear channel.

Annex 2, "NVNG MSS Uplink Band Sharing Analysis" provides calculation of the probability of interference to a LMS receiver from MES transmissions, given that the dynamic channel assignment technique has failed to identify an active channel for the reasons given above, or for any other reason. The results apply to both analog and digitally modulated LMS systems, operating in the bands 138-174 MHz, 406-420 MHz, 450-512 MHz, 806-821 MHz, 821-824 MHz, 851-856 MHz, and 866-869 MHz, provided that the technical characteristics are consistent with those used in the model.

3.2 Potential interference from non-GSO MSS earth stations into land mobile stations

The analysis assumed multiple worst case conditions: 1) non-GSO MSS mobile earth stations (MESs) transmitting at 100% of capacity, 24 hours per day, 2) terrestrial stations and non-GSO MSS MESs geographically clustered in the same areas, and 3) dynamic channel avoidance not effective. Appendix B of Annex 2 describes the modeling and simulations used in the analyses.

For the worst case conditions stated, if the land mobile station is operated at push-to-talk rates of 0.01 Erlang, the land mobile station would experience a mean time between interference events of 2.5 days. For a variety of channelization plans, MES bit rates, and terminal distributions, the mean time between interference events for a typical land mobile user was found to range from 10 hours to 21 months. The analog FM land mobile user would observe the interference event as a single "click" or "pop". For digital FSK receivers, operation below the demodulator threshold results in an increased bit error rate and degraded voice quality. Since in general the non-GSO MSS network will be able to identify active mobile channels, the actual interference from non-GSO MSS MESs into a given land mobile station will be much less than that calculated under the worst case assumptions used.

The results of the analysis are now used to calculate the probability of interference with dynamic channel assignment in use. For the case of a low power LMS system where the transmitter power is not high enough to be detected by the band-scanning receiver, the interference probabilities would be as calculated in Annex 2. For the case of signal blockage causing the dynamic channel assignment technique to not identify an active channel, the interference probability would be as calculated in Annex 2 but multiplied by p_b (the probability of signal blockage.) p_b is certainly less than one, and may typically be in the range 0.1-1.0%. For the case of a LMS transmitter beginning operation in what had previously been a clear channel, the interference probability would be as calculated in Annex 2 but multiplied by p_c (the probability of a free channel being used by a MES and then also being selected for use by an LMS system). p_c is less than one, and may be in the range 0.1 to 0.25). Thus, in the identified cases where the dynamic channel assignment technique fails to fully prohibit the possibility of interference, the probability of interference from MES transmitters to LMS mobile receivers may be acceptably low, for LMS systems that can accept 0.1% additional degradation of availability. While the analyses were performed using mobile